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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE EFFECT OF SEAL SHAPE VARIATIONS
UPON THE PERFORMANCE OF THE
XR-3 CAPTURED AIR BUBBLE TESTCRAFT

by

Robert William Moloney

March 1975

Thesis Advisor: D. M. Layton

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The report contains a brief description of the testcraft plus a more thorough description of the installed air spring seal and seal shape control mechanisms. A short description of the data gathering and reduction systems is also included.

(continued)

The report then presents data in graphical form showing the changes in the thrust (or drag) versus velocity characteristics as the shapes of the air spring seals are varied. Finally, the conclusions that may be drawn from the data presented.

The Effect of Seal Shape Variations
Upon the Performance of the
XR-3 Captured Air Bubble Testcraft

by

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Submitted in partial fulfillment of the
requirements for the degree of

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March 1975

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I. INTRODUCTION

In future decades the United States Navy will have a requirement for very high speed surface combatants capable of speeds well in excess of fifty knots. It is clear that because of their high drag, conventional displacement hulls cannot achieve this goal with any powerplant of reasonable size. One particularly viable alternative to the displacement hull is the surface effect ship. The U. S. Navy presently has an active program of research into the characteristics of these vessels. As a part of this effort, the Naval Postgraduate School has, under the sponsorship of the Surface Effects Ships Project Office (SESPO), operated the XR-3 captured air bubble testcraft in a series of test programs since the summer of 1970.

This report focuses on one series of these tests. The purpose of this series of tests was to determine the effects of seal shape and position upon the performance of the XR-3. All tests were performed at the San Antonio Lake, California test site between August 1974 and February 1975.

A. DESCRIPTION OF THE XR-3

The XR-3 testcraft operated by the Naval Postgraduate School is a captured air bubble type of surface effect ship. It has an overall length of 24 feet, a beam of 12 feet, and weighs approximately 6000 pounds in the test configuration with a crew of two.

The most apparent physical feature of the testcraft is its twin hull construction, which is similar to that of a catamaran vessel. Flexible, inflated air sping seals are installed between the side hulls

at the bow and stern of the testcraft. These seals, together with the side hulls form a sealed plenum chamber beneath the testcraft. Pressurization of the plenum creates a large aerostatic lift force, which supports about 80% of the total testcraft weight. The remaining lift is provided principally by the displacement lift of the side hulls. The side hulls draw between two and ten inches of water, depending upon the testcraft weight and center of gravity. Due to the pressure existing in the plenum, the water level inside is lower than the exterior level.

The plenum is pressurized by five axial fans, each driven by a small air cooled internal combustion engine. Two engines are used to pressurize the plenum directly, while two more are used to selectively pressurize the bow seal or the plenum. The fifth engine selectively pressurizes the stern seal or the plenum, and in addition, drives an automotive type alternator to provide 12 volt d.c. power for the ships systems.

Power for the data systems is provided by a 110 volt, 1500 watt a.c. generator located on deck aft of the lift engine compartment.

Propulsion is provided by two 40-horsepower outboard motors located on the aft end of the side hulls, outboard of the stern seal. The outboard motors are configured so that the port and starboard propellers rotate in opposite directions, in order to minimize propeller side force effects on the testcraft.

Although the XR-3 has positions for two crew members, the pilot controls all maneuvering and data collection functions; the observer has no specific duties.

B. THE AIR SPRING SEAL

1. Description

The air spring seals currently in use on the XR-3 were installed during the winter of 1972-1973, replacing the older semi-rigid seals. The new seals were designed and fabricated for the XR-3 by the Naval Ships Research and Development Center.

The bow and stern seals on the XR-3 are identical, with minor differences in the rigging of the position control cables. Each seal consists of a two-cell rubberized fabric air bag attached to the underside of the plenum (the wet deck). Twelve 48" x 4" x 1/4" spring steel stiffeners are installed in the lower surface of the seal to give shape and reinforcement to the seal. (See Fig. 2) The fabric divider between the cells is perforated to control the rate of airflow from one cell to the other, and thus provides a certain amount of rate damping of the seal motion. The seals may be selectively pressurized to a high pressure, to provide a high spring constant for the seal, or to a minimum pressure for a low spring constant.

2. Position Control Mechanism

Two downstop rings are located on each of the spring steel stiffeners. One of these is located six inches forward of the trailing edge, and the second 30 inches forward of the trailing edge.

On the bow seal, each of the forward downstop rings is attached by a short length of steel cable to a steel bar that runs athwartships the full width of the seal. The aft downstop rings are ganged to a second bar in an identical manner. Each of these bars is connected by two steel cables to an electrically operated winch. The capstan of this winch is divided into two sections, each having a different diameter.

The diameters of the capstan sections have been chosen so that by winding the cables from the forward downstops on the smaller section and those from the aft downstops to the larger part, the seal may be raised evenly, rotating about the hinge line. (Figures 3 and 4)

In contrast, the forward and aft downstop rings on the stern seal are not ganged. Instead, the downstop limit of each of the stiffeners may be adjusted individually by means of twelve small hand cranked winches located on the stern of the XR-3. The forward and aft downstop cables on each individual stiffener are attached to the small and large diameter sections of the corresponding hand winch. With this type of rigging it is possible to vary the downstop limits of each stiffener individually, allowing contouring of the stern seal shape in the lateral direction, if desired. (Figures 5 and 6)

C. SEAL SHAPE

The contours of the air spring seals in both the pressurized and unpressurized states are shown in Figures 7 through 10. The installed shape of the bow and stern seals are nearly identical, being slightly bowed. When pressurized, the bowed shape of both seals becomes much more pronounced.

II. TESTING PROCEDURES

A. GENERAL

The purpose of this series of tests was to investigate the effects of variation in seal shape upon the performance of the XR-3, and to determine the optimum seal shape, if such an optimum exists. To this end, a series of test runs was conducted to determine the thrust (or drag) to velocity relationship that existed for each individual seal configuration. These thrust-velocity curves were then compared to determine the effects of seal shape.

B. DATA ACQUISITION

An extensive instrumentation system is available aboard the XR-3. Sensors are installed to measure thrust, velocity, angular displacements and rates about all axes, accelerations, plenum and seal pressures, rudder angle, and height of a reference point above water. In this series of tests, the parameters of interest were thrust and velocity.

1. Thrust Measurement

The thrust of each outboard motor is transmitted to a balanced-bridge load cell by a parallelogram linkage, which ensures that only longitudinal forces are read. The output of the load cell is amplified to a range of 0.0 to 1.0 volt d.c. compatible with the onboard tape recorder. This voltage range corresponds to a thrust range of 0 to 500 pounds.

2. Velocity Measurement

The testcraft velocity is measured by a Potter velocity meter located on a supporting strut in the undisturbed water ahead of the

testcraft. (See Figure 1) This device is a flowmeter consisting of a small magnetized free turbine in an axial duct in the bomb shaped probe. The rotating turbine wheel induces a sinusiodal voltage in a pickup coil located in the body of the probe. The frequency of this signal is directly proportional to the flow through the meter, so also to the testcraft velocity. A velocity conditioning unit, which contains a frequency to voltage converter, produces a signal of 0.0 to 5.0 volts d.c. corresponding to testcraft velocities of 0 to 40 knots. The signal is then split, one branch being reduced in voltage to a range of 0.0 to 1.0 volts d.c. compatible with the data recording system. The other signal is used to drive a d.c. voltmeter, which has been calibrated in knots, located on the pilot's instrument panel.

3. Data Recording

All data taken onboard the XR-3 are automatically recorded on a Pemco model 120-B magnetic tape recorder. This recorder will simultaneously record fourteen channels of data from the electronic sensors plus the comments and observations of the pilot on a voice edge track. The input range for each channel is -1.0 to +1.0 volts d.c. with an accuracy of 1/2%. The recording unit, located in a compartment immediately aft of the pilot's cockpit, is controlled by means of a remote control panel on the pilot's instrument panel. The 110 volt a.c. generator supplies power to the recorder through a Pemco power supply which provides the 26 volt d.c. power required by the recorder. In addition, a digital voltmeter is connected to the data inputs through a rotary selector switch enabling the pilot to monitor the input to any channel. The easy portability of the Pemco recorder allows it to be taken from the XR-3 to the mobile data facility at the completion of each day's operations so that the data may be immediately reduced and analyzed.

Reference 1 contains additional information on the data collection and recording system.

C. DATA REDUCTION

The XR-3 mobile data facility is contained in a 26-foot Champion motor home. A portion of the interior furnishings have been removed and a complete data reduction system installed. In addition to the data reduction facilities and working space, the motor home provides berthing and messing for XR-3 personnel during extended operations.

Power for the data systems in the mobile facility is supplied by a self contained gasoline powered 110 volt, 5000 watt a.c. generator. A Pemco power supply is used to provide power to the tape recorder, while all other equipment uses the 110 volt a.c. power directly.

In addition to the tape recorder, the data reduction equipment in the mobile facility consists of:

1. Signal selector and conditioning unit
2. Analog to digital converter and calculator interface module
3. Monroe model 1880 calculator
4. Monroe model PL-4 digital X-Y plotter
5. Hewlett-Packard model 7100-B two-channel strip chart recorder

The signal selector and conditioning unit is the heart of the data reduction system. It conditions the raw analog data from the tape recorder to supply the proper signals to the strip chart recorder and to the Monroe calculator for display on the Monroe X-Y plotter. The signal conditioning unit accepts fourteen raw analog inputs from the fourteen channels of data on the tape recorder. A selector panel allows the operator to output any given parameter on any of nine output channels. In addition, a summing circuit is provided which is utilized to provide

a total thrust signal by combining the port and starboard thrust signals. The unit also provides a means for adjusting the null and range of the conditioned output, and filters out high frequency noise from the data. Any two channels of analog data may be displayed on the strip chart recorder.

The conditioned analog data may also be converted to digital form for further calculations on the Monroe claculator, or to be plotted on the X-Y plotter.

A more thorough description of the data reduction system is presented in Ref. 2.

D. SEAL SHAPE CONTROL

Control over the shape of the seals was exercised by use of the electric bow seal winch and the manual stern seal winches. During this series of tests, the shape of the bow seal was varied by restricting the downward travel of the forward set of downstops without restricting the travel of the trailing edge of the seal. This was accomplished by disconnecting the rear downstop cables from the winch and stopping off these cables. In this configuration, with the XR-3 out of the water, as the forward downstop was raised the shape of the seal was observed to become noticeably less bowed, with the trailing edge moving downward about two inches as the forward downstop was raised through it's entire range of travel. Figure 11 shows the forward downstop position as a function of the seal count.

The stern seal downstop position was a linear function of the seal count, each increase/decrease of 20 counts from the base setting (1000) raising/lowering the seal 1.25 inches.

E. TEST RUNS

The test runs were conducted so as to obtain thrust vs. velocity curves for several seal positions, with the weight and center of gravity remaining as constant as possible during the runs.

Prior to each day's operations, the voice track of the tape recorder was annotated with the date, crew, weight, center of gravity, data channelization, and any other information deemed necessary. Calibration signals were applied to all channels to enable accurate setting of the null and range on the data reduction equipment. Known loads of 0, 250, and 500 pounds were applied to the thrust load cells, and a zero velocity signal was recorded. After the XR-3 was waterborne, a twenty-knot velocity calibration point was also recorded.

Prior to each individual run of the series, the pilot prefaced the tape with the data for that run. This included weight, center of gravity, seal position, and any other factors such as wind and sea conditions that may affect the conduct of the test. During the run, thrust and velocity were continuously recorded. Upon changing from one velocity to another, the pilot would observe the velocity input on the digital voltmeter. When the velocity had stabilized, the pilot would mark the point with the phrase "Data Point" on the voce track. This mark was usually supplemented by the observed velocity which served as an additional check when reducing the data.

All tests were conducted in calm water conditions, and as nearly as possible in calm wind conditions. The magnitude of the aerodynamic drag forces on the XR-3 are not known, but because of the size of the vessel, they are certainly significant. In order to minimize the variations in aerodynamic drag between upwind and downwind runs, tests were conducted only in calm to very light wind conditions.

The following is a summary of the test runs conducted:

DATE	RUN #	WEIGHT	C.G.	FWD. SEAL	AFT SEAL
16 Aug 74	4101	5948	121.8	0.0	0980
"	4102	"	"	"	0990
"	4103	"	"	"	1000
"	4104	"	"	"	1010
"	4201	"	"	0.85	Relaxed
"	4202	"	"	3.5	"
"	4203	"	"	3.0	"
"	4204	"	"	1.95	"
24 Oct 74	4105	6050	118.25	0.0	"
"	4106	"	"	1.115	"
"	4107	"	"	2.05	"
"	4108	"	"	2.6	"
"	4109A	"	"	3.0	"
15 Nov 74	4109	6050	119.0	0.0	"
"	4110	"	"	1.0	"
"	4111	"	"	2.0	"
"	4112	"	"	2.3	"
"	4113	"	"	3.0	"
"	4114	"	"	2.3	1050
06 Dec 74	4115	6010	119.0	0.0 T.E.up	Relaxed
"	4116	"	"	1.0 T.E.up	"
"	4117	"	"	2.0 T.E.up	"
"	4118	"	"	1.5 T.E.up	"
"	4119	"	"	2.0 T.E.up	"
18 Feb 75	4121	6000	119.0	Relaxed	Relaxed

In runs 4115 through 4119, the trailing edge of the bow seal was raised two inches above it's unrestrained position, and the position of the forward downstop was varied as before. This was in an attempt to discover the effects of a more rounded trailing edge shape.

Run 4121 was conducted to provide a definitive description of the performance of the XR-3 with no seal shape control. This run was used as a base against which all other runs were compared.

III. RESULTS

Figures 12 through 16 present the data collected in each series of test runs. Each plot shows the shape of the thrust vs. velocity curve for a number of different seal positions, but at a constant testcraft weight and center of gravity position.

Upon examination of each of these plots, the following may be observed:

1. Runs 4201 through 4204 (Fig. 12): The bow seal position 0.85 requires the least thrust at velocities below about 18 knots, but above that speed the seal position 1.95 requires less. The two highest seal positions, 3.0 and 3.5 require significantly higher thrust throughout the velocity range.

2. Runs 4101 through 4104 and 4114 (Fig. 13): Significantly higher thrust levels are required as the downward travel of the stern seal is restrained. For instance, raising the downstop from 0980 to 1050 increases the thrust required by approximately 20% at 16 knots.

3. Runs 4105 through 4109A (Fig. 14): At speeds below approximately 21 knots all runs are tightly grouped and exhibit little variation with seal position. At speeds greater than 21 knots the unrestrained seal requires significantly less thrust.

4. Runs 4109 through 4113 (Fig. 15): Variation of the bow seal position between the values of 0.0 and 2.3 results in only minor changes in thrust required. Raising the seal to the 3.0 position, however, increases the thrust required greatly.

5. Runs 4115 through 4119 (Fig. 16): At velocities below 18 to 20 knots, the results were nearly identical with those obtained in runs 4109-4113 which were at the same weight and center of gravity. Above 20 knots, the more rounded trailing edge shape with a seal count of 0.0 has much better performance.

In general, within each series of runs, the effects of variation of the bow seal downstop position between zero and approximately 2.3 are slight and inconsistent. It appears that the unrestrained bow seal provides performance that is optimum under most conditions, but that slight variations of seal position do not change the thrust required significantly. Conversely, restraint of the bow seal downstop to positions above 3.0 appears to incur significant drag penalties.

It is also to be noted that the overall thrust level with the center of gravity at 121.8 inches is significantly greater than with the center of gravity in the more optimum 118- to 119-inch range. Reference 3 provides a further discussion of the effects of center of gravity variation. In addition, variation of the seal position at this center of gravity position provokes a greater change in required thrust than in the case of an optimum center of gravity position.

IV. CONCLUSIONS

From the data presented, the following conclusions have been drawn:

1. Of the seal shapes tested, the rounded trailing edge (rear downstop up two inches) and forward downstop setting of 0.0 provided the best performance in terms of thrust required.
2. Small deviations from optimum seal position result in only minor changes in thrust required.
3. Significant restraint of the bow seal forward downstop incurs large drag penalties, and should be avoided.
4. Any restraint of the stern seal degrades performance significantly, and should also be avoided
5. If the XR-3 is operating at a non-optimum center of gravity, it is much more sensitive to deviation from optimum seal position.

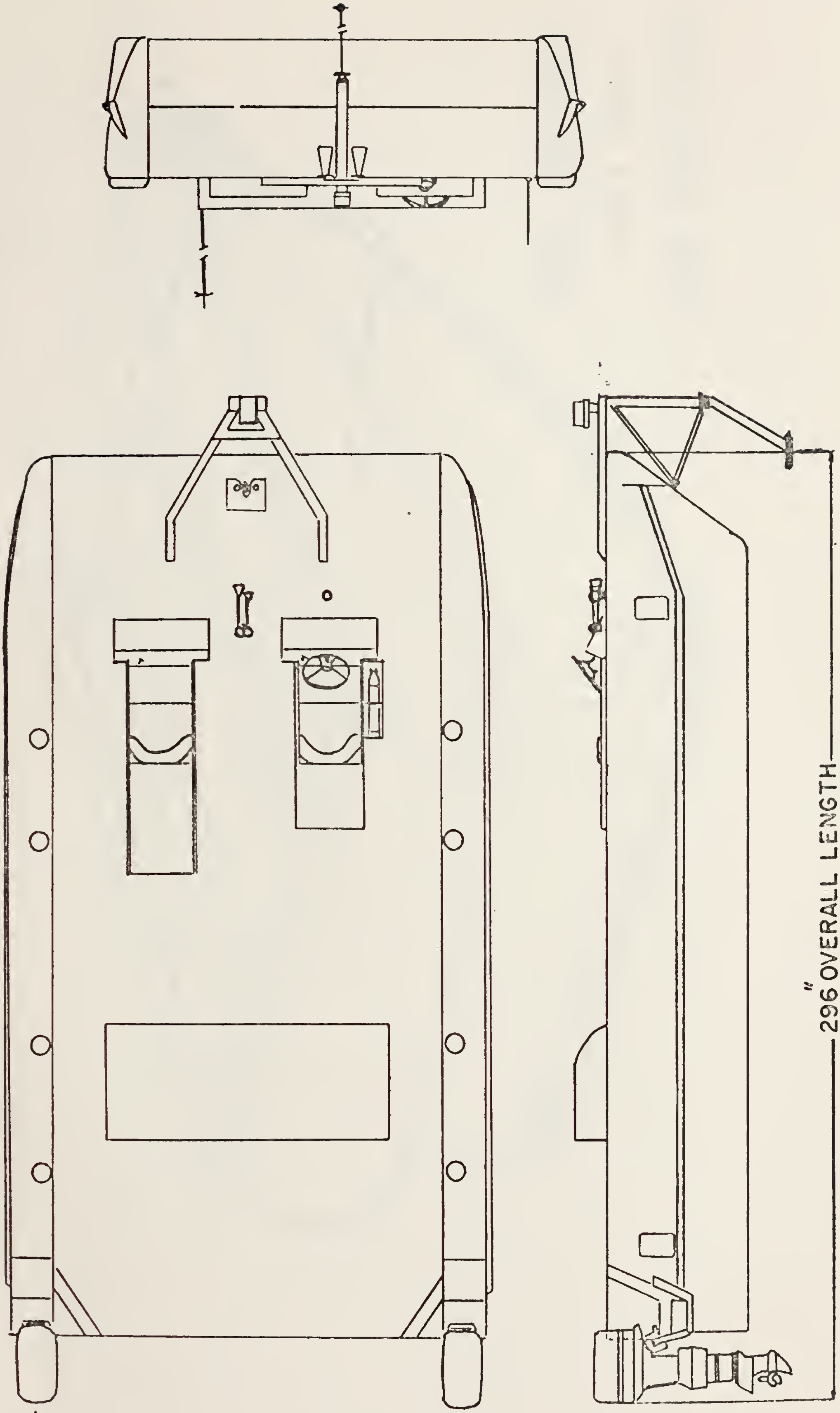


Figure 1: General Configuration of the XR-3

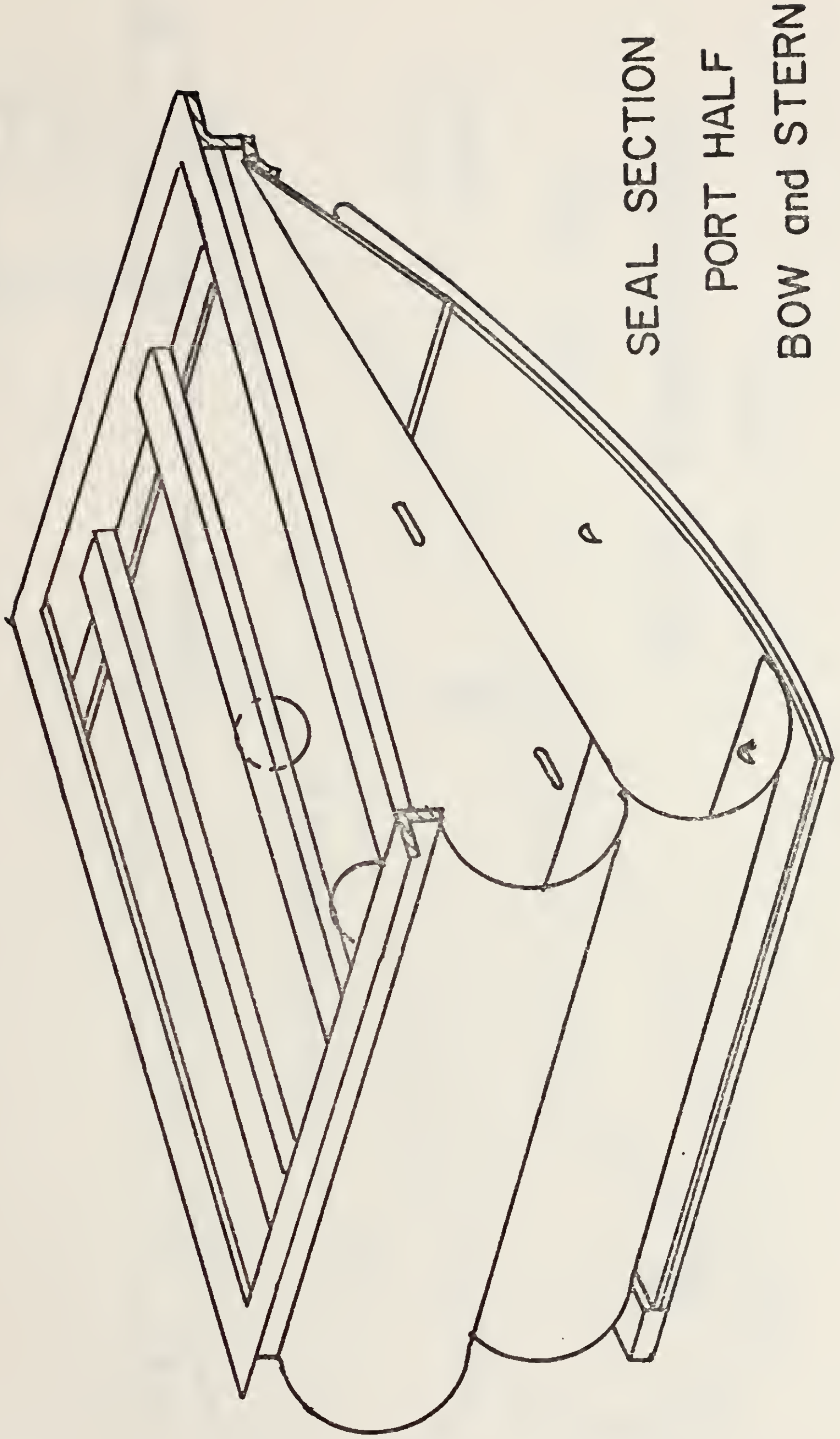
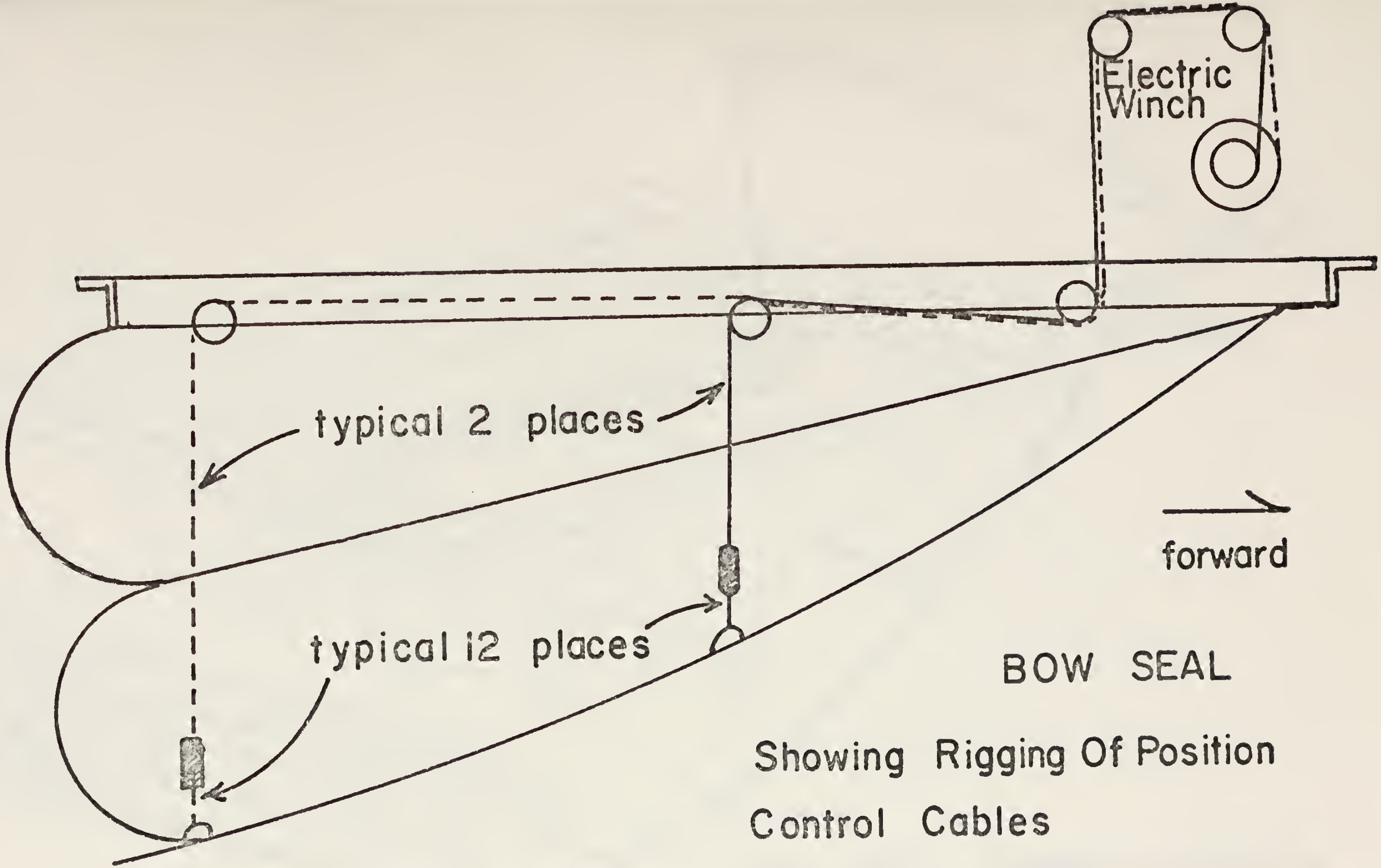


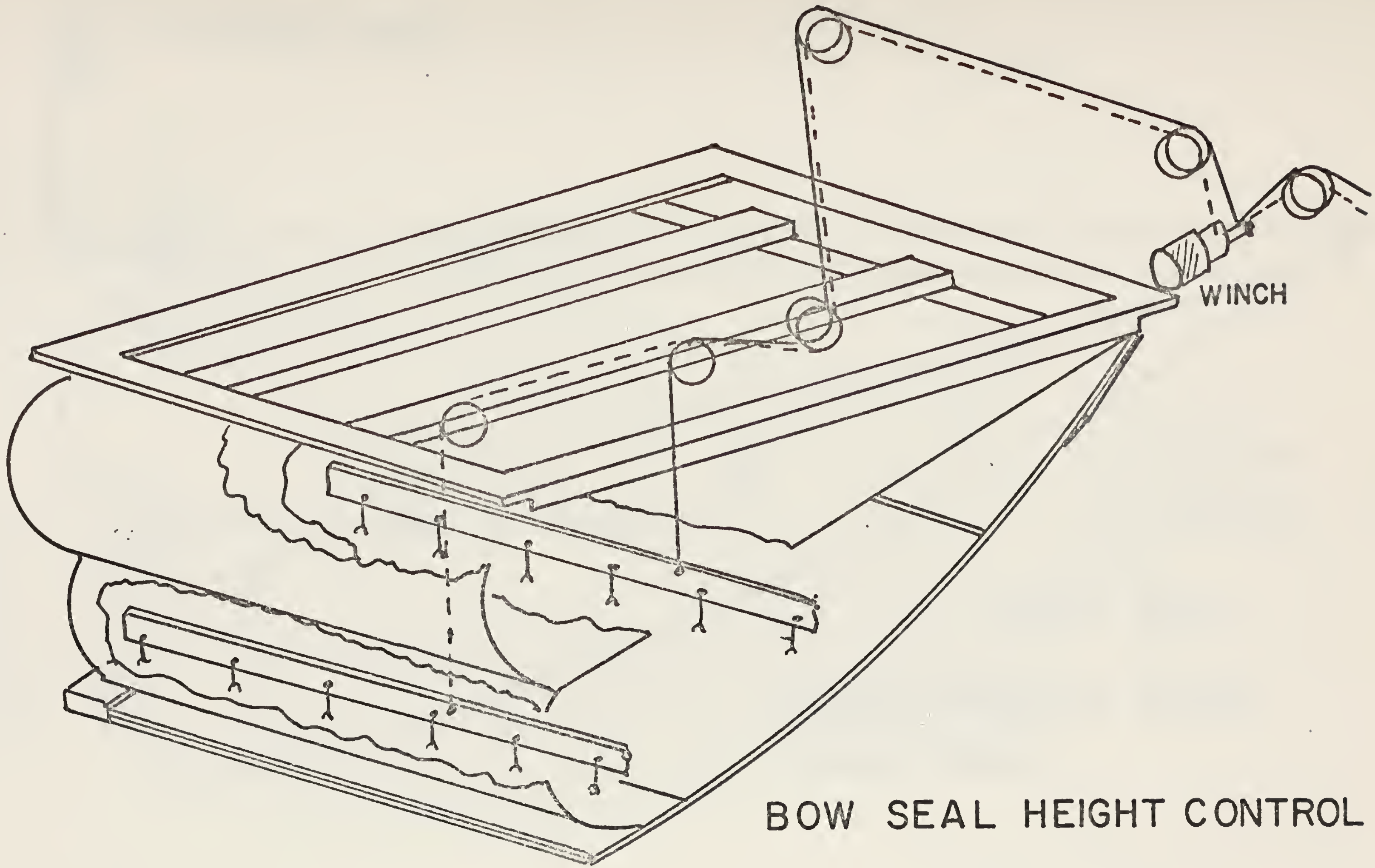
Figure 2



BOW SEAL

Showing Rigging Of Position Control Cables

Figure 3



BOW SEAL HEIGHT CONTROL

PORT HALF

Figure 4

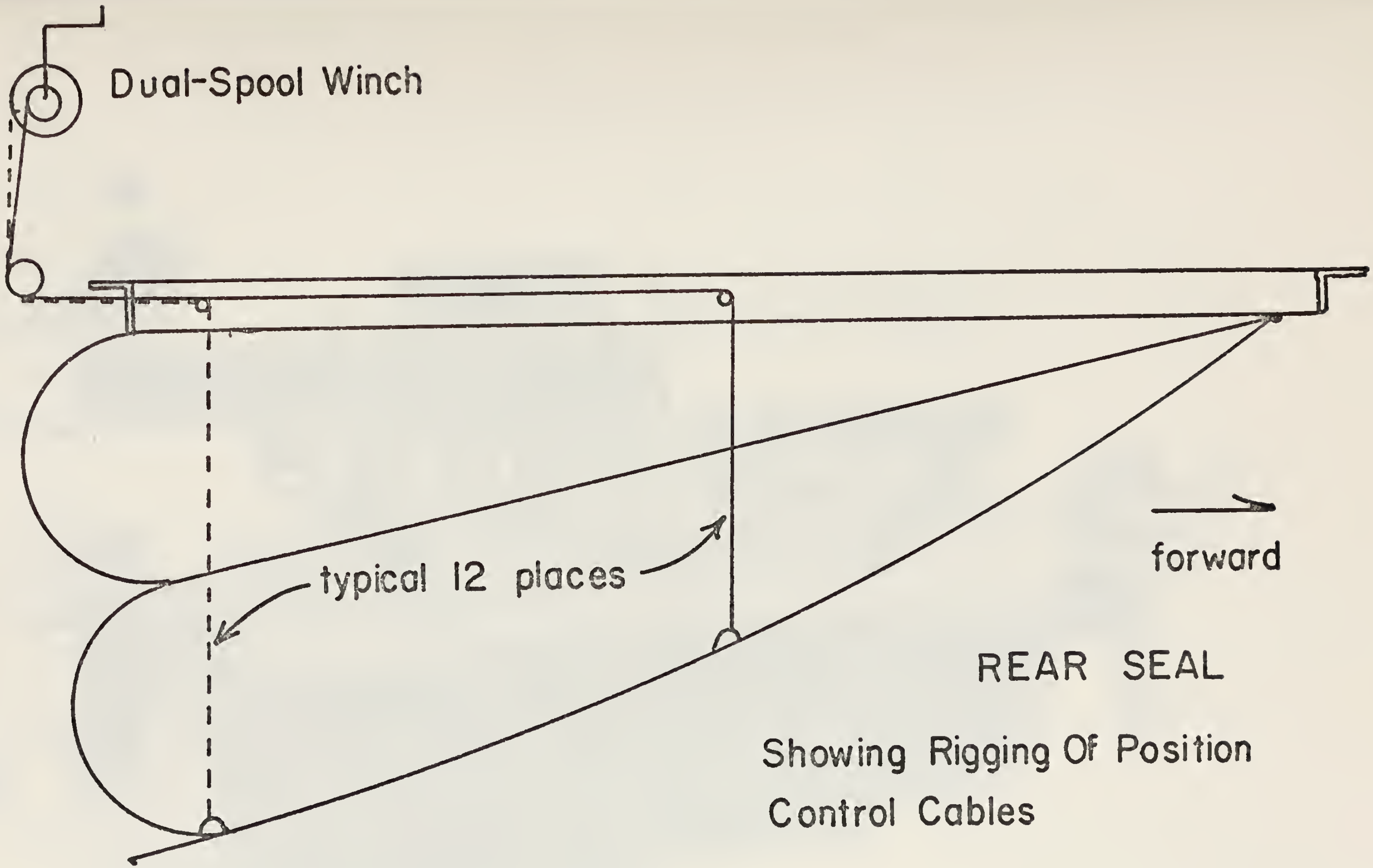

Dual-Spool Winch
typical 12 places
forward
REAR SEAL
Showing Rigging Of Position
Control Cables

Figure 5

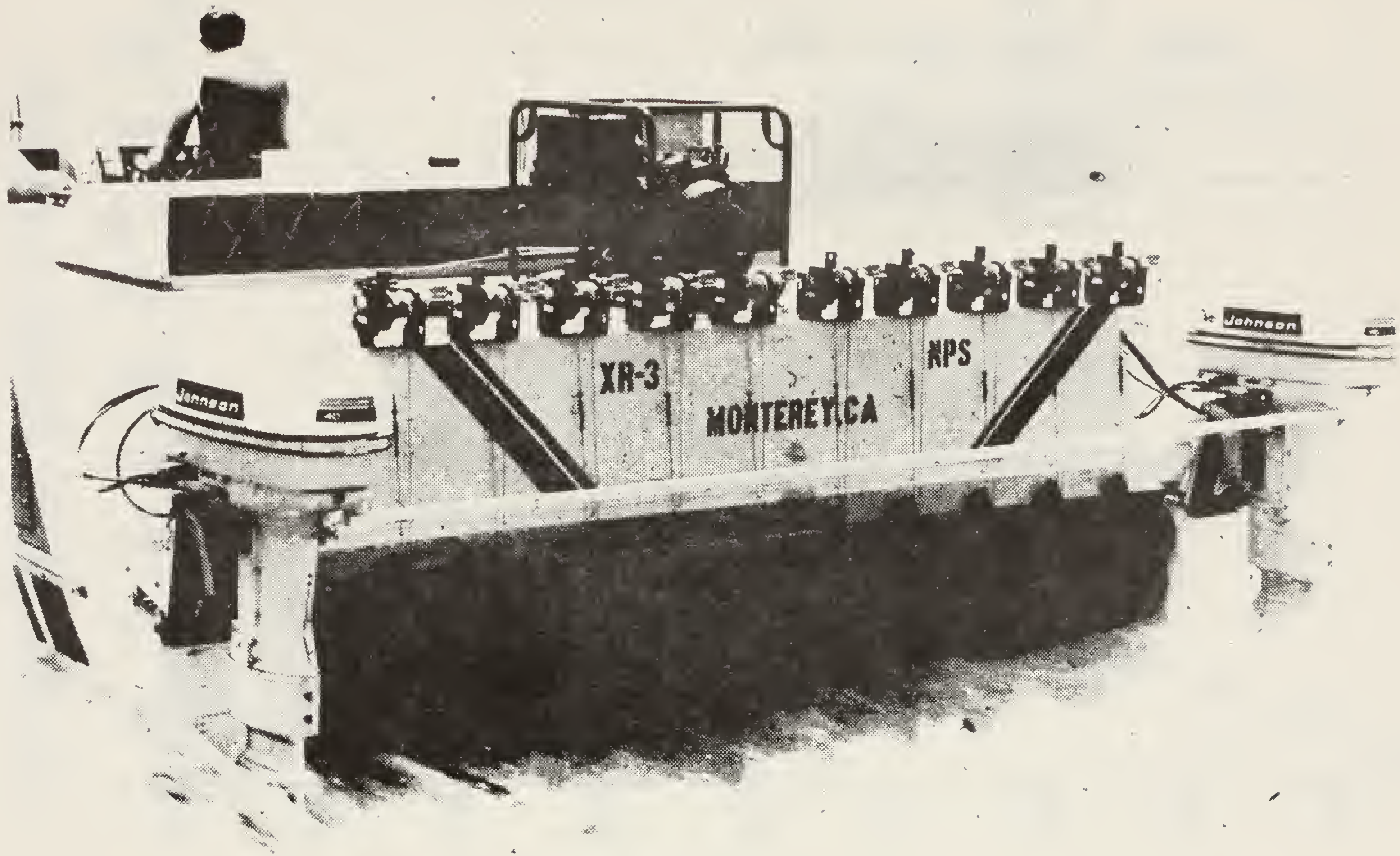


Figure 6: Aft Seal Position Control Winches

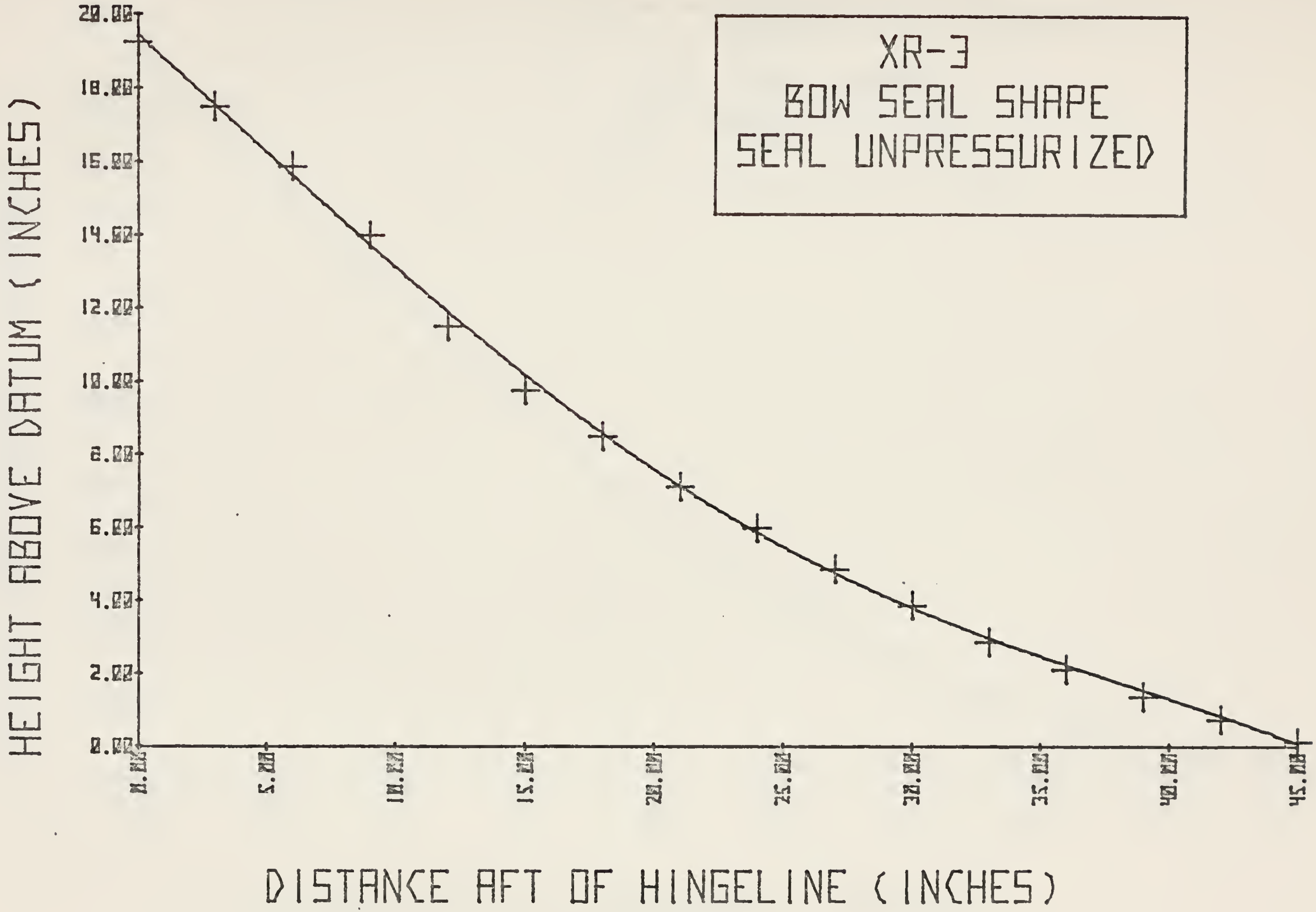

XR-3
BOW SEAL SHAPE
SEAL UNPRESSURIZED
HEIGHT ABOVE DATUM (INCHES)
DISTANCE AFT OF HINGELINE (INCHES)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00

Figure 7

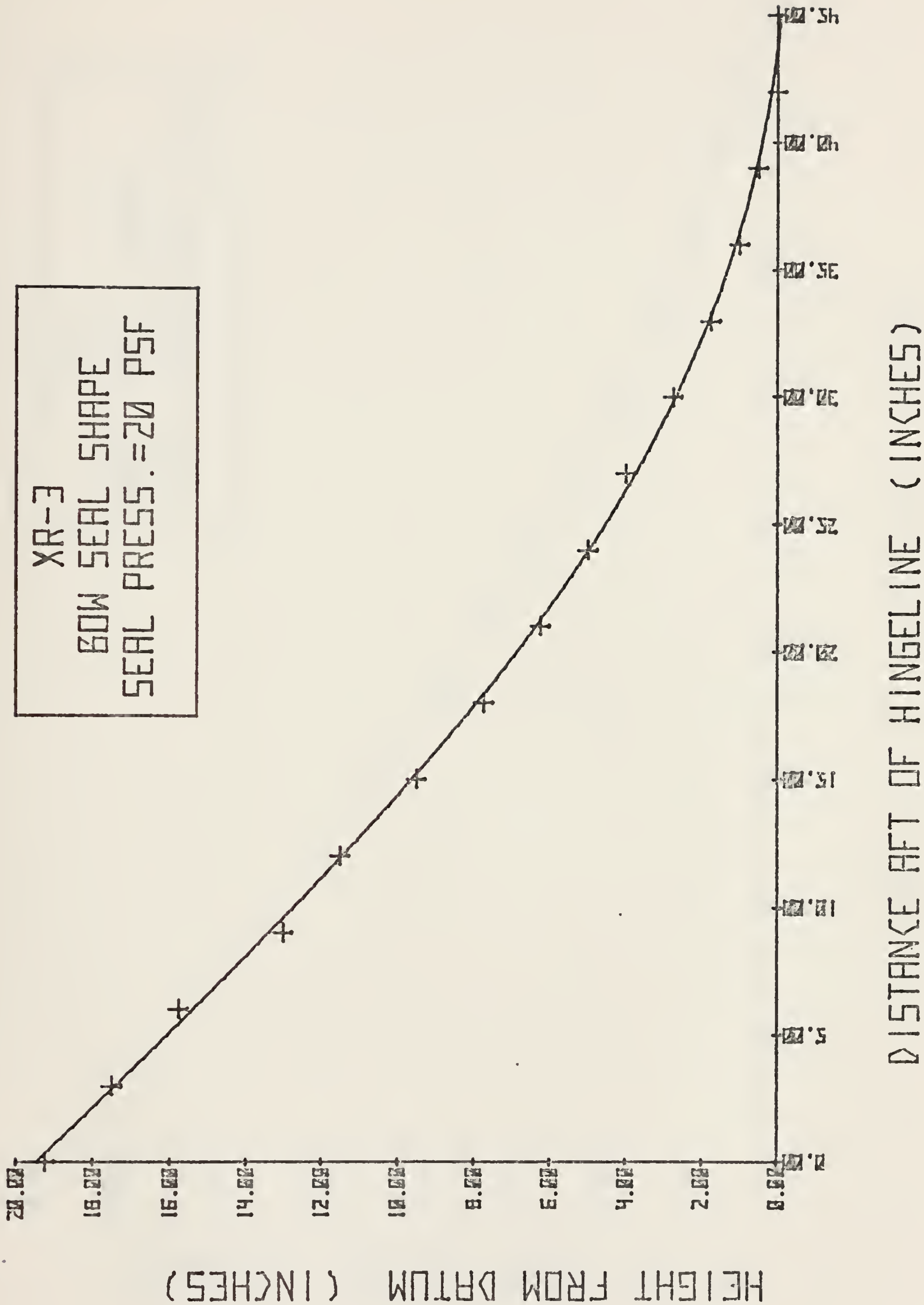

XR-3
BOW SEAL SHAPE
SEAL PRESS.=20 PSF
HEIGHT FROM DATUM (INCHES)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
DISTANCE AFT OF HINGELINE (INCHES)

Figure 8

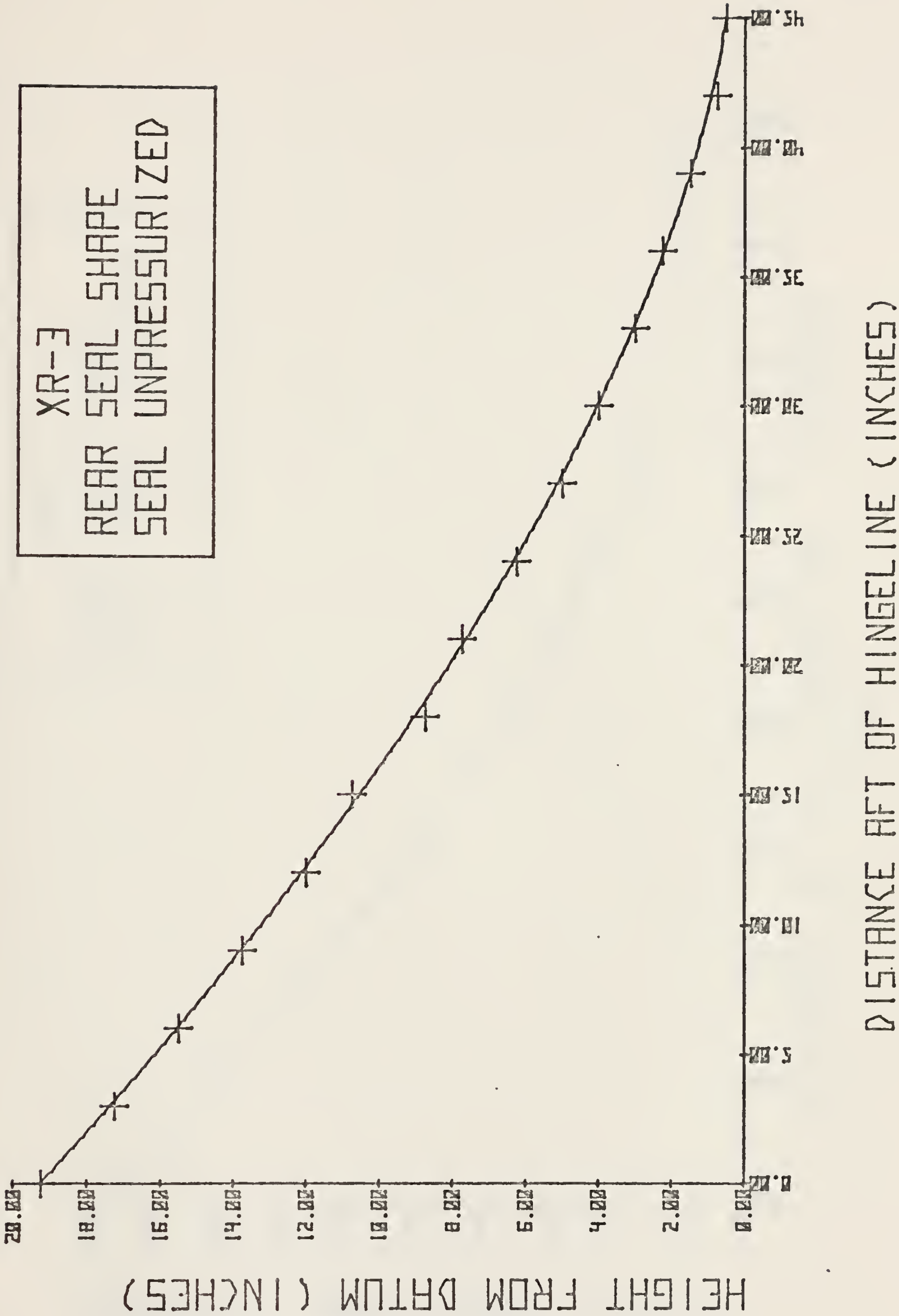
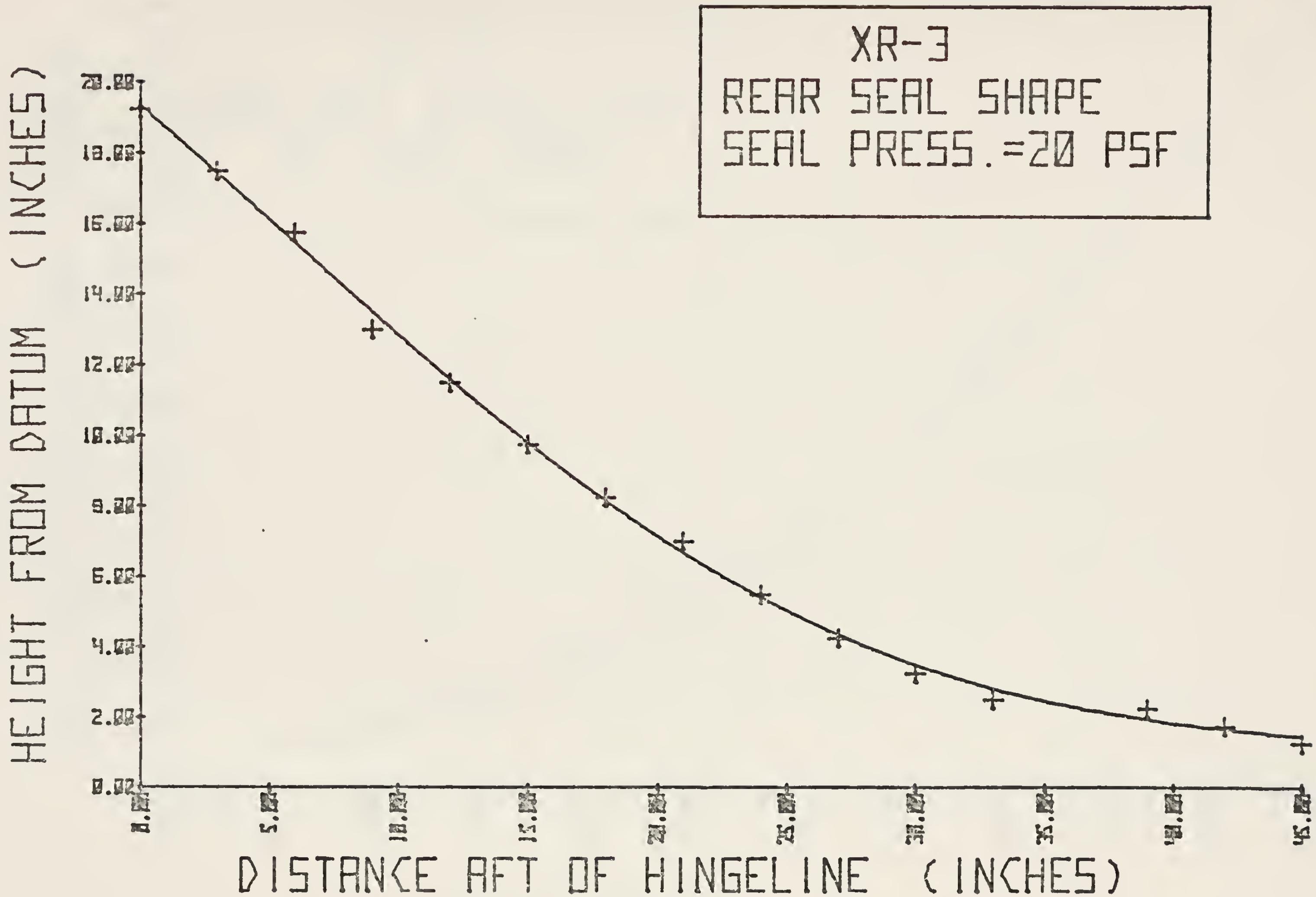

XR-3
REAR SEAL SHAPE
SEAL UNPRESSURIZED
HEIGHT FROM DATUM (INCHES)
DISTANCE AFT OF HINGELINE (INCHES)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00

Figure 9



XR-3
REAR SEAL SHAPE
SEAL PRESS.=20 PSF
HEIGHT FROM DATUM (INCHES)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
DISTANCE AFT OF HINGELINE (INCHES)

Figure 10

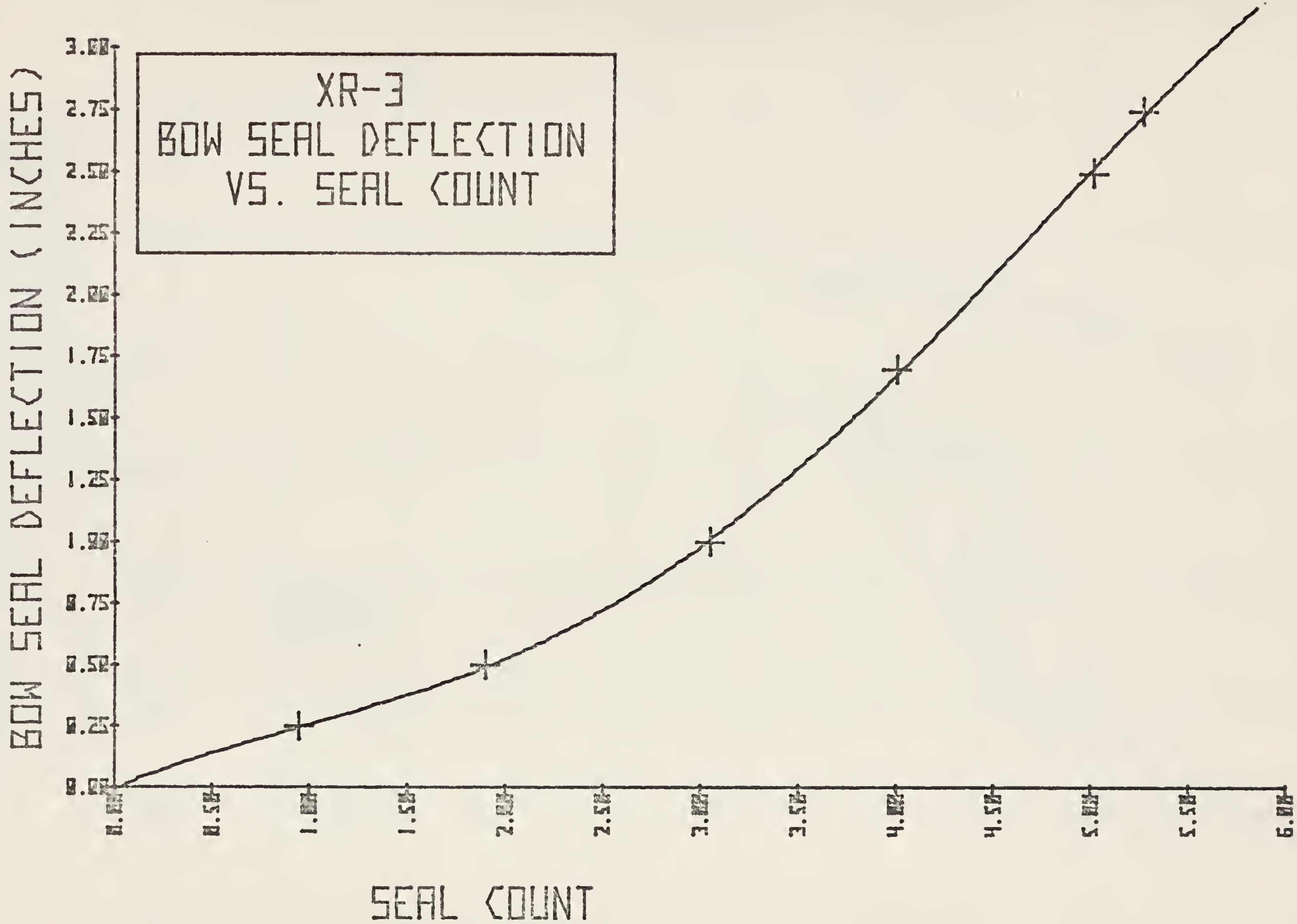
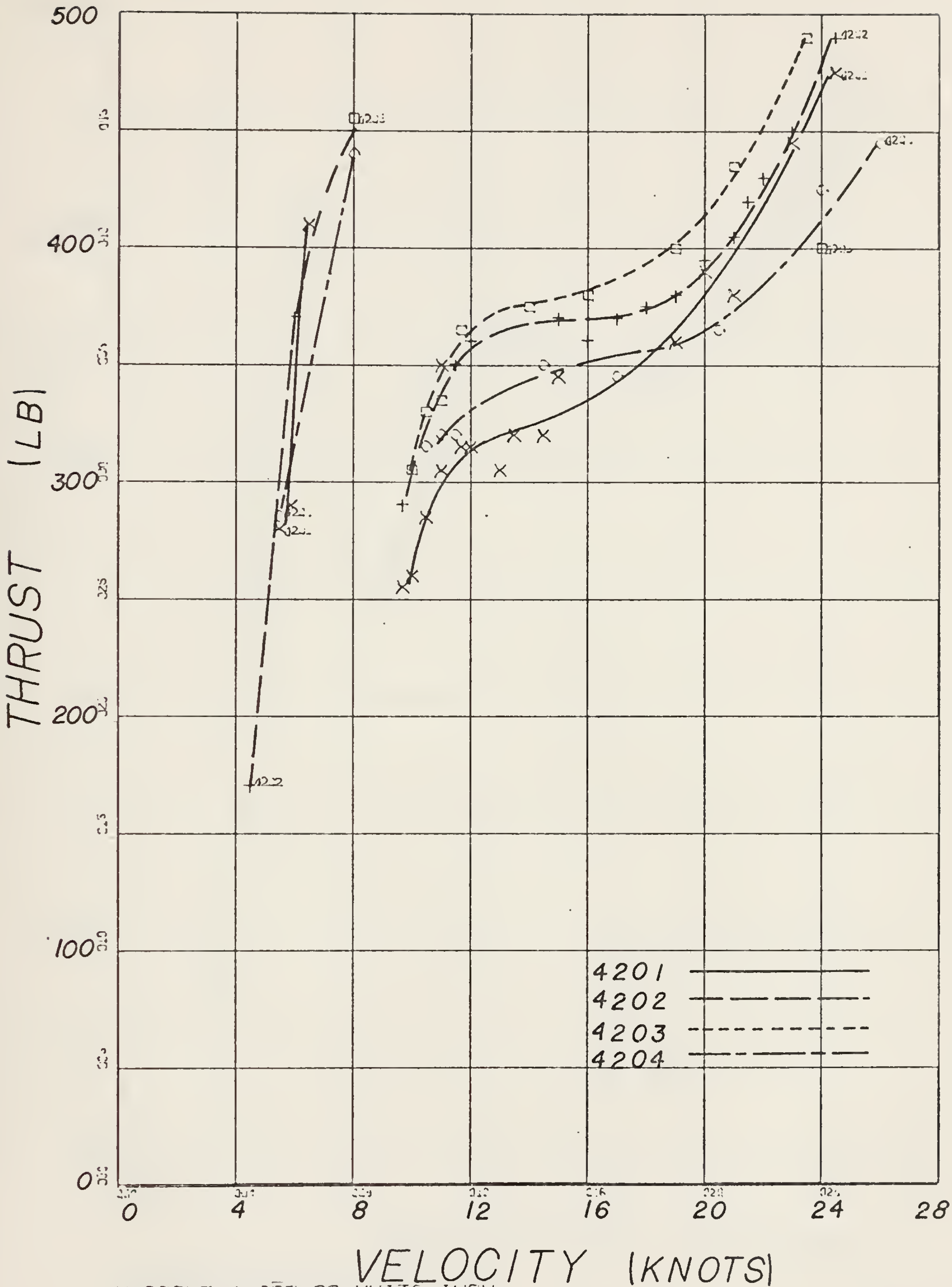

XR-3
BOW SEAL DEFLECTION
VS. SEAL COUNT
BOW SEAL DEFLECTION (INCHES)
SEAL COUNT
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

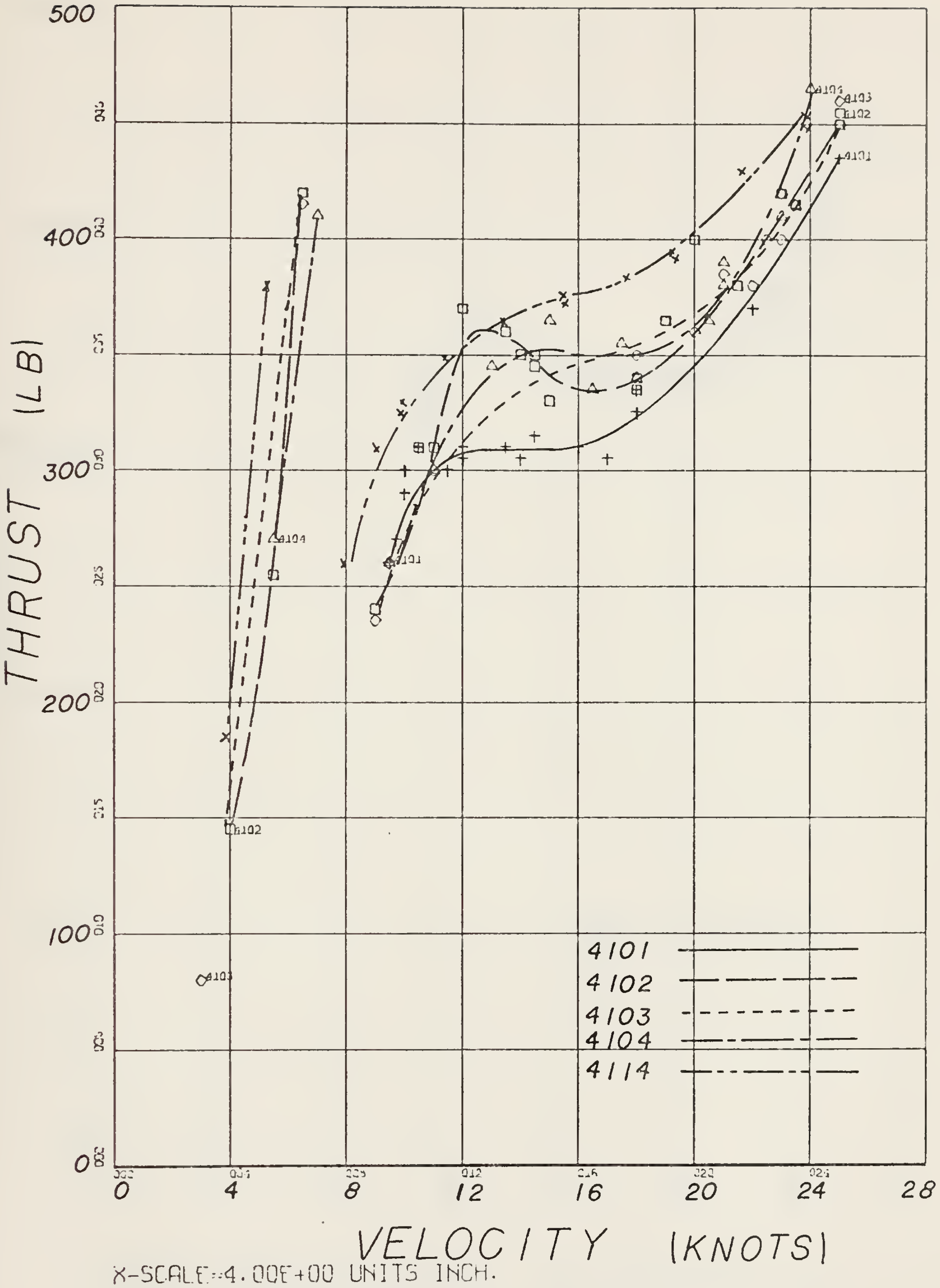
Figure 11



X-SCALE=4.00E+00 UNITS INCH.
Y-SCALE=5.00E+01 UNITS INCH.

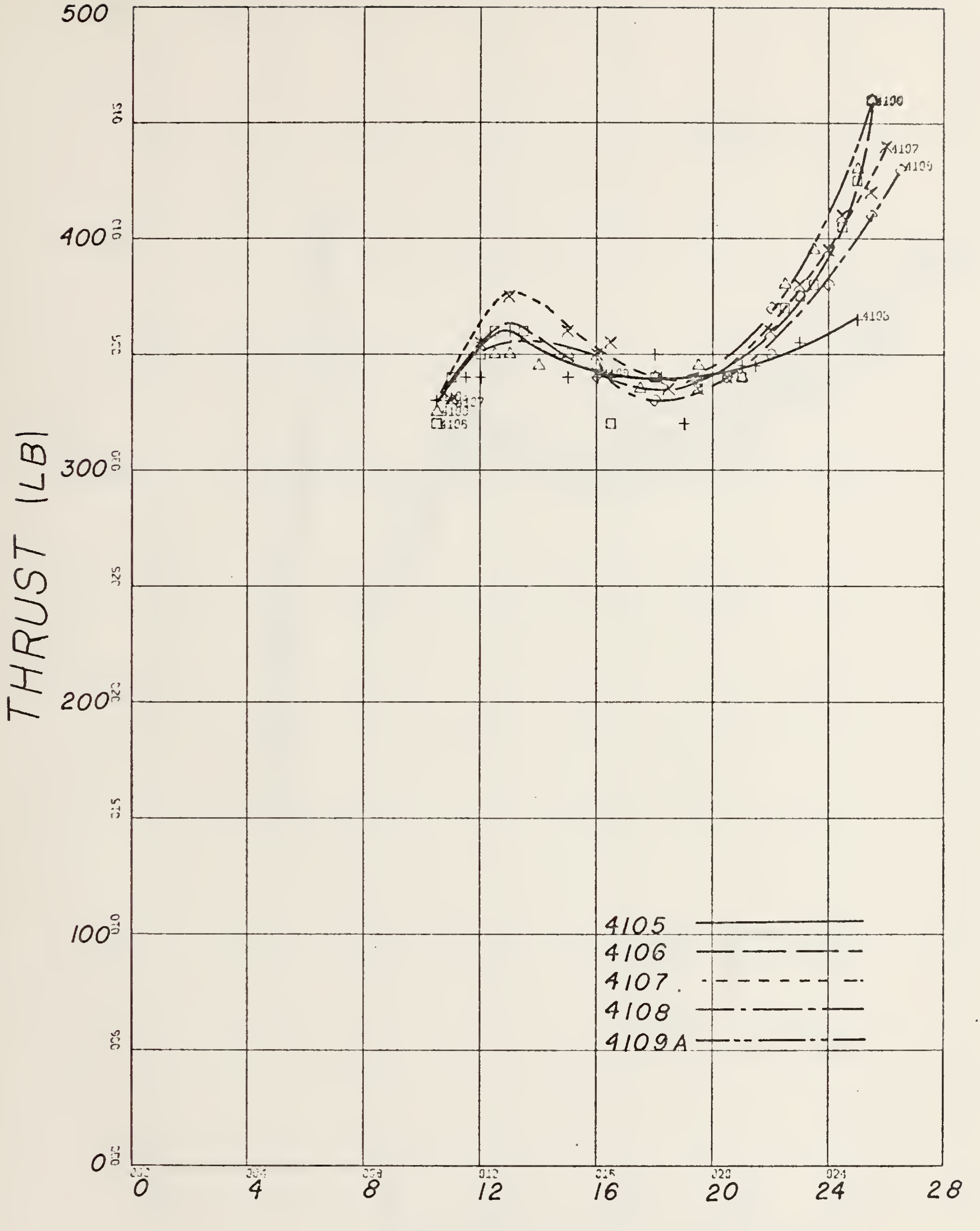
XR-3 16 AUG 1974 WT=5950 CG=121.8
BOW SEAL VRBL STERN SEAL RELAXED

FIGURE 12



X-SCALE=4.00E+00 UNITS INCH.
Y-SCALE=5.00E+01 UNITS INCH.
XR-3 16 AUG 1974 WT=5948 CG=121.8
BOW SEAL RELAXED   STERN SEAL VRBL

FIGURE 13



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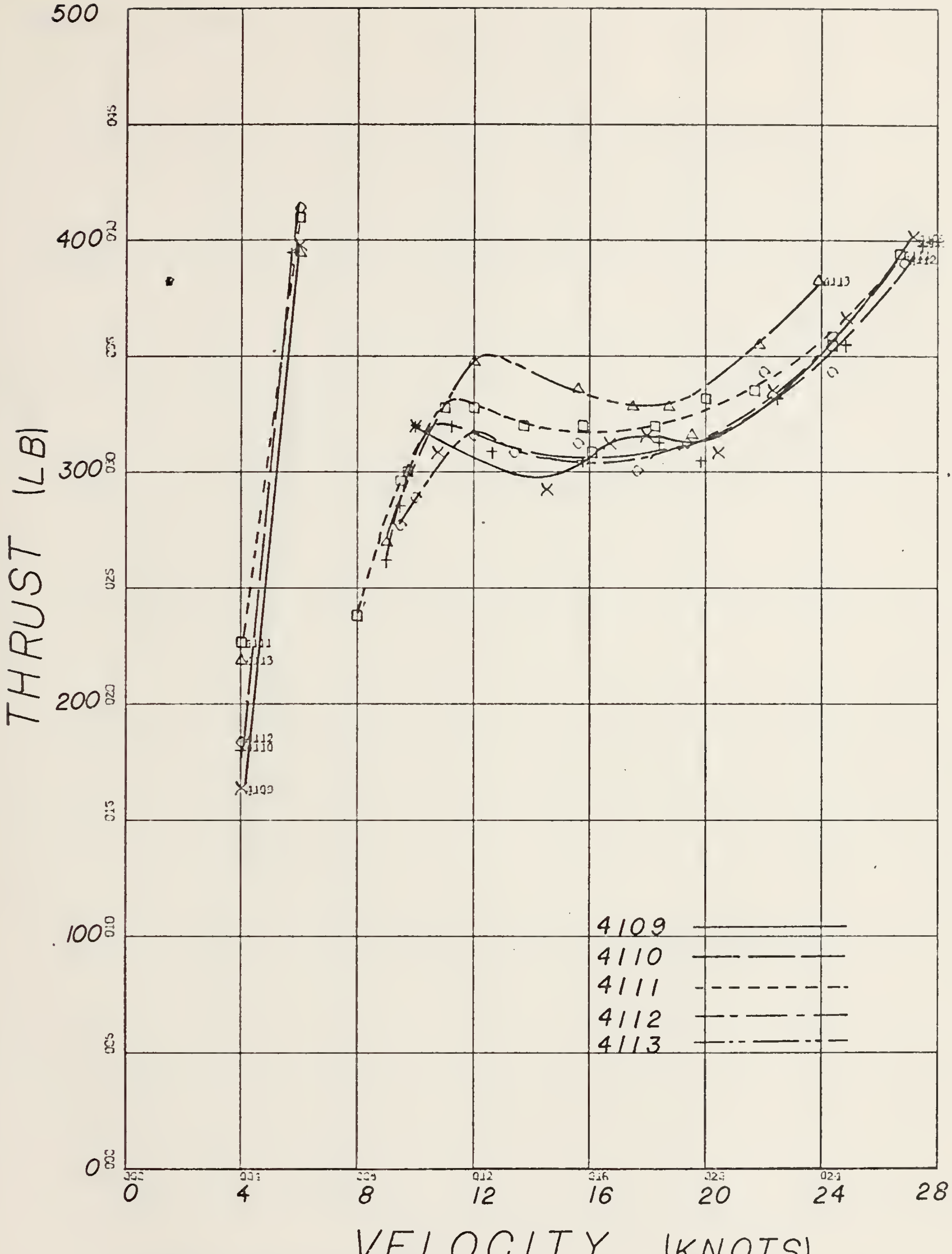
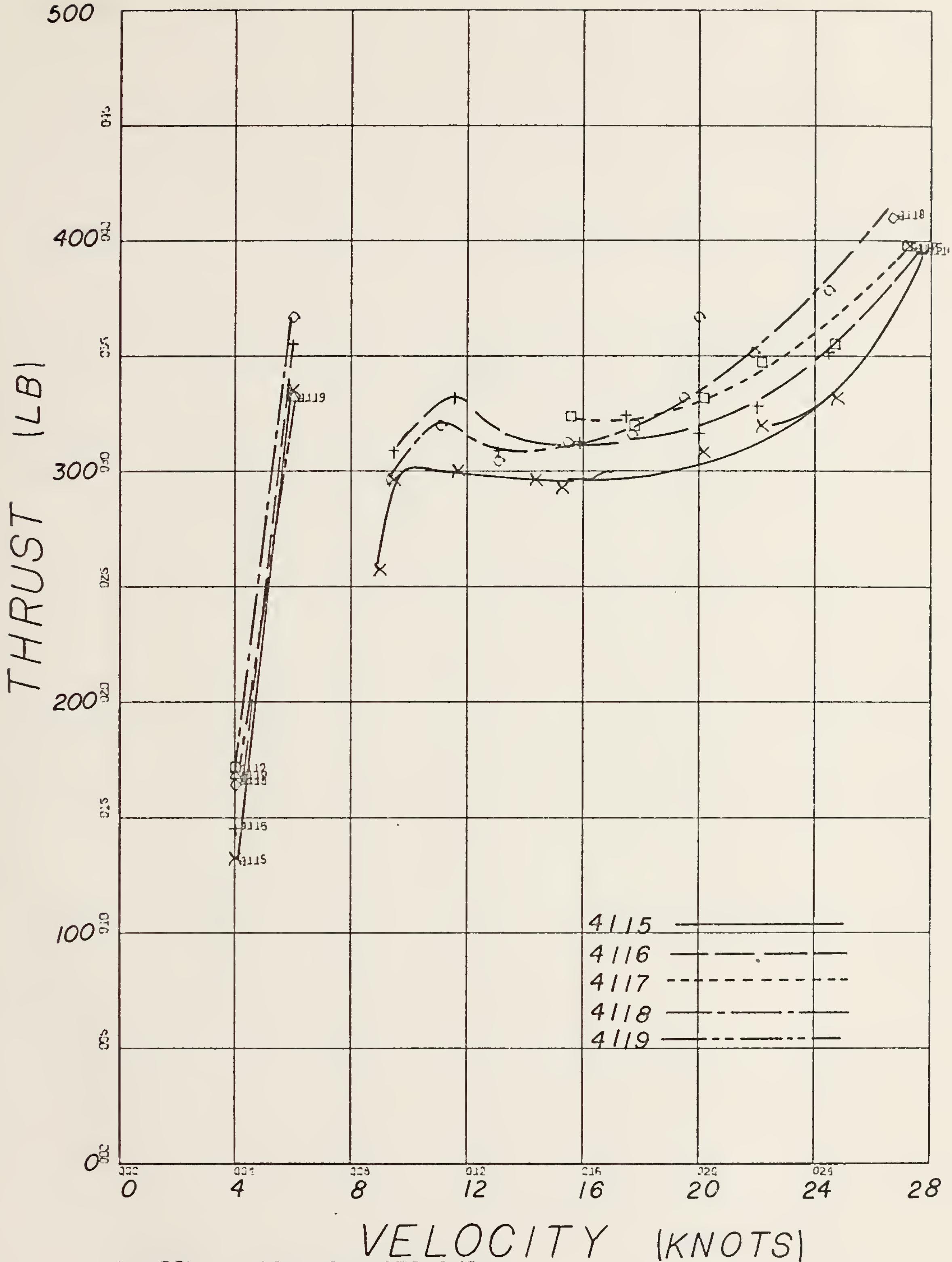
XR-3 24 OCT 1974 WT=6050 CG=118.25
BOW SEAL VRBL STERN SEAL RELAXED

FIGURE 14



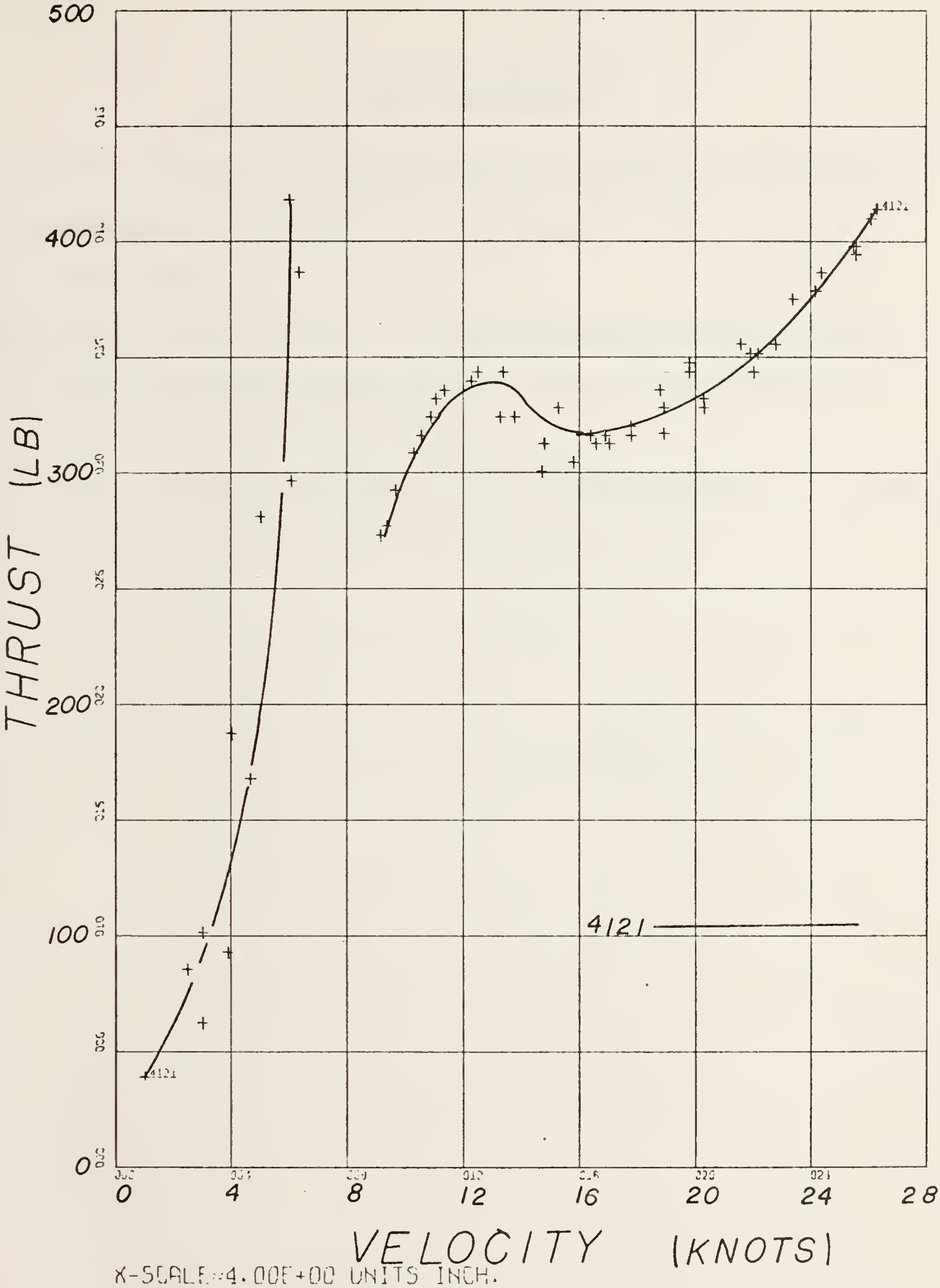
X-SCALE=4.00E+00 UNITS INCH.
Y-SCALE=5.00E+01 UNITS INCH.
XR-3 15 NOV 1974 WT=6050 CG=119.0
FWD SEAL VRBL REAR SEAL RELAXED

FIGURE 15



X-SCALE=4.00E+00 UNITS INCH.
Y-SCALE=5.00E+01 UNITS INCH.
XR-3 6 DEC 1974 WT=6010 CG=119.0
BOW SEAL VRBL STERN SEAL RELAXED

FIGURE 16



X-SCALE=4.00E+00 UNITS INCH.
Y-SCALE=5.00E+01 UNITS INCH.
XR-3 18 FEB 1975 WT=6000 CG=119.0
BASE PERFORMANCE BOTH SEALS RELAXED

FIGURE 17

LIST OF REFERENCES

1. Feeney, James Leo, XR-3 Data Acquisition System for Performance Evaluation, M.S. Thesis, Naval Postgraduate School, Monterey, March 1972.
2. Dabberi, Peter Vincent Jr., Data Reduction System for the XR-3 Captured Air Bubble Testcraft, M.S. Thesis, Naval Postgraduate School, Monterey, December 1973.
3. Leins, William, XR-3 Center of Gravity Characteristics, M.S. Thesis, Naval Postgraduate School, Monterey, March 1975.

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